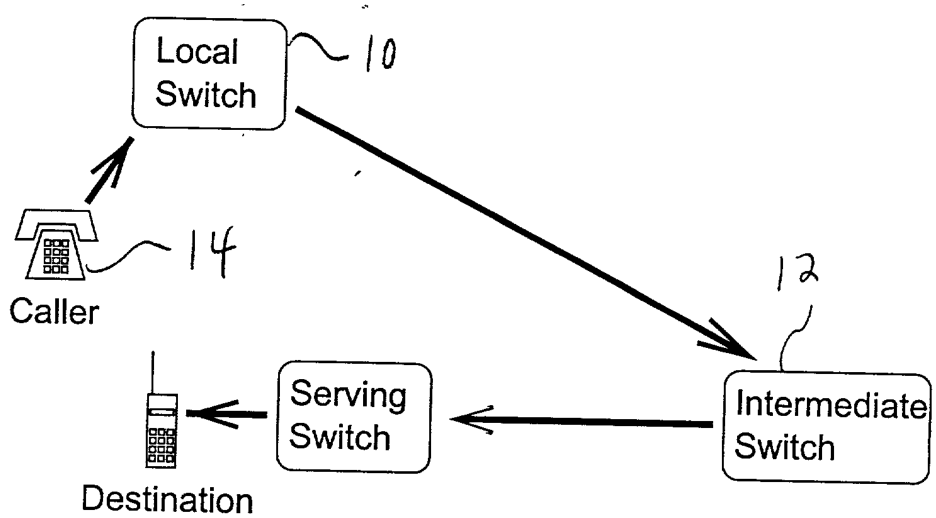

Local
Switch
10
14
Caller
12
Serving
Switch
Intermediate
Switch
Destination

Fig. 1

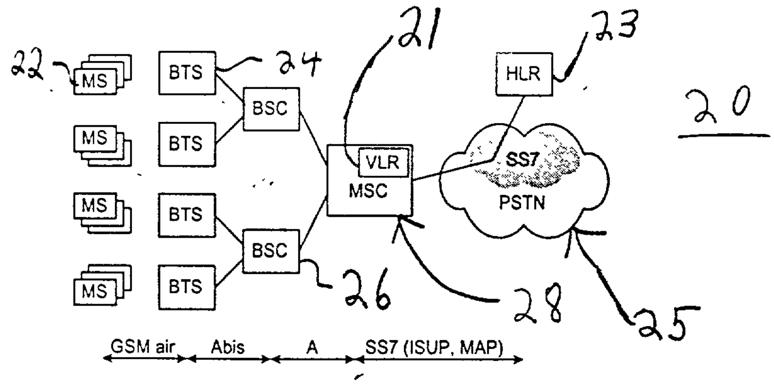

22
MS
MS
MS
MS
BTS
BTS
BTS
BTS
24
BSC
BSC
26
21
VLR
MSC
28
23
HLR
SS7
PSTN
25
20
GSM air
Abis
A
SS7 (ISUP, MAP)

Fig. 2

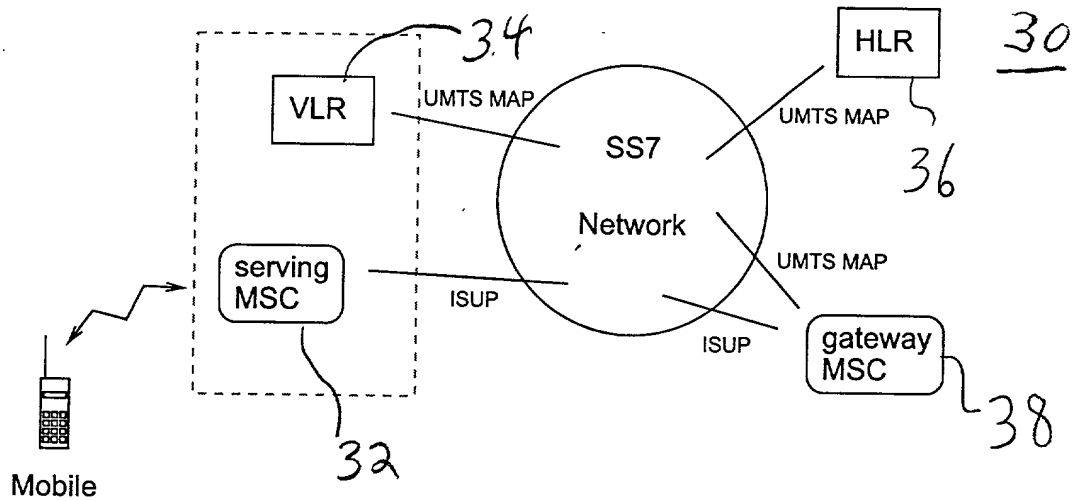

34
VLR
UMTS MAP
SS7
Network
HLR
30
UMTS MAP
36
serving
MSC
ISUP
UMTS MAP
ISUP
gateway
MSC
38
32
Mobile

Fig. 3

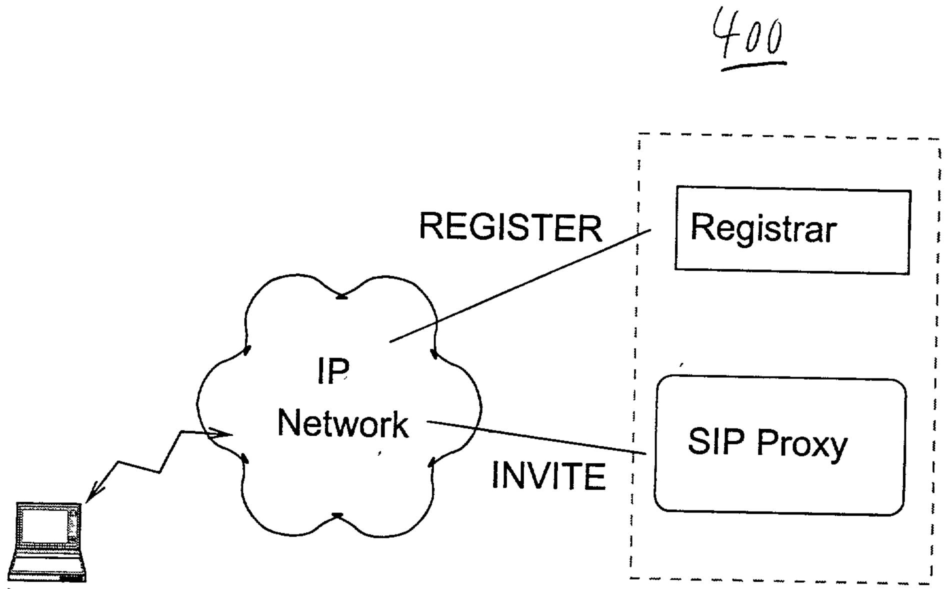


Fig. 4

Analogous entities in SIP and UMTS

UMTS	SIP
HLR	Registrar
Gateway MSC	Home proxy server
Serving MSC	End system (for REGISTER)
MSISDN	User address (in INVITE)
IMSI	User address (in REGISTER)
MSRN	Device address

Fig. 5

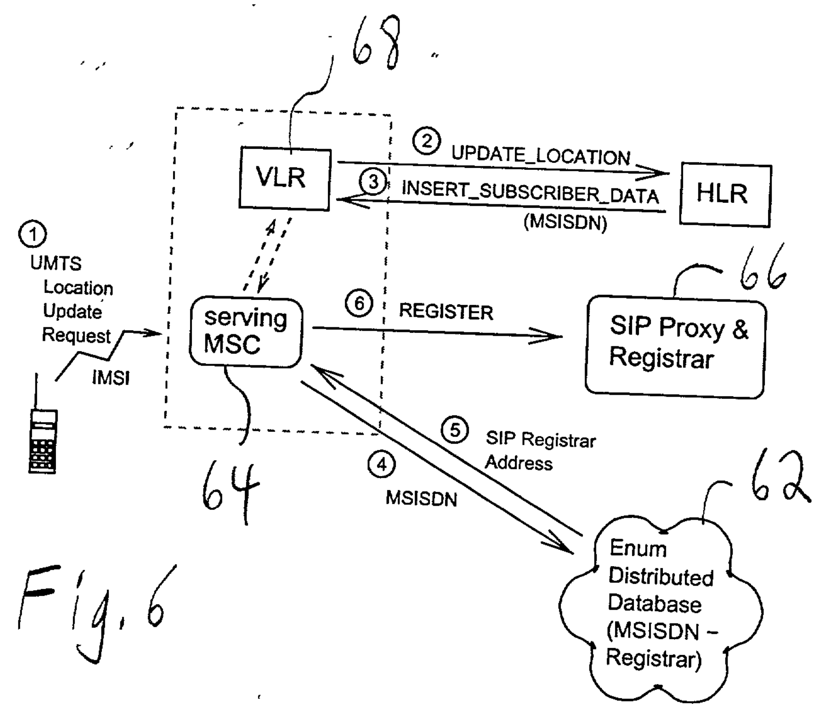

68
VLR
HLR
2 UPDATE_LOCATION
3 INSERT_SUBSCRIBER_DATA
(MSISDN)
1
UMTS
Location
Update
Request
IMSI
serving
MSC
6 REGISTER
SIP Proxy &
Registrar
66
5 SIP Registrar
Address
4
MSISDN
64
62
Enum
Distributed
Database
(MSISDN -
Registrar)

Fig. 6

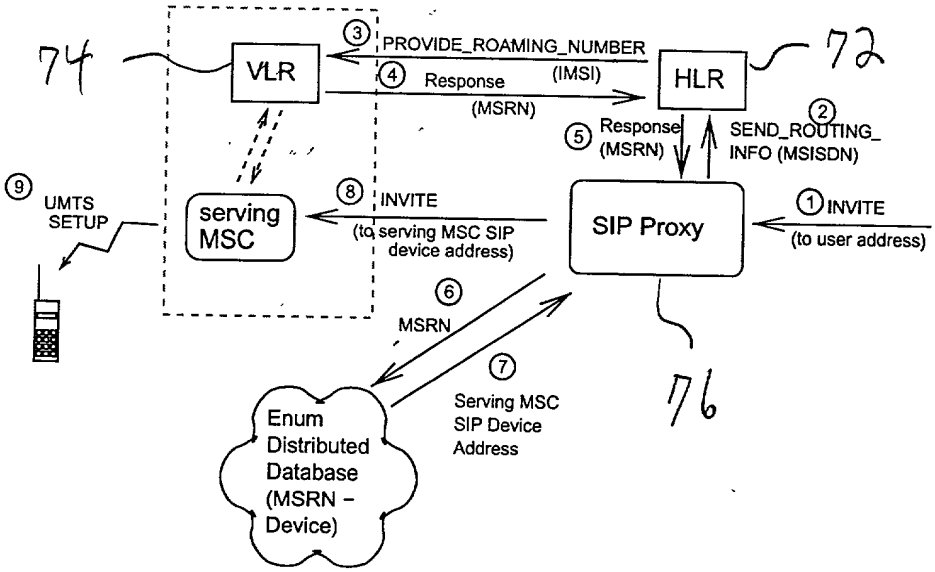


Fig. 7

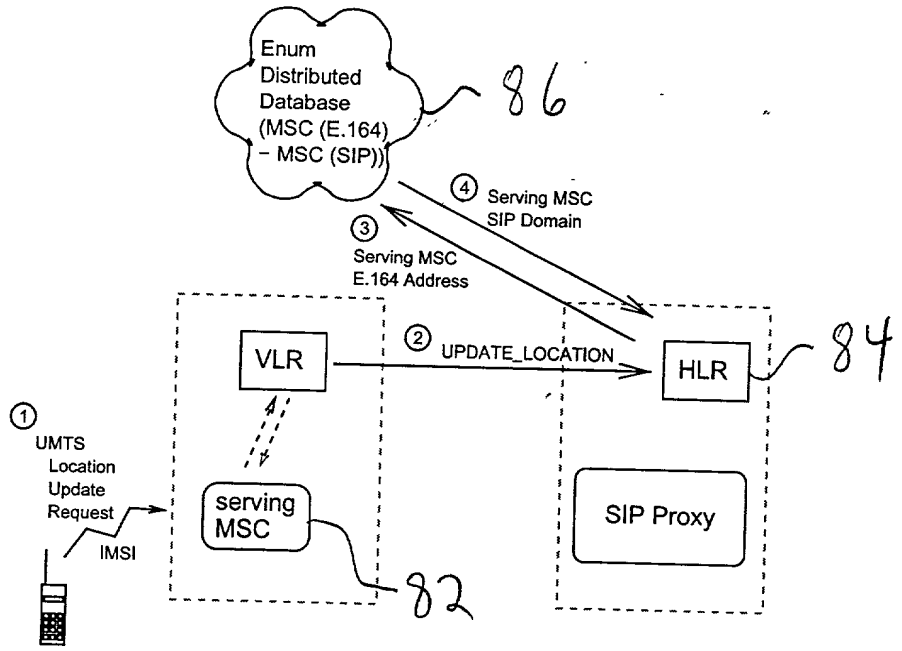

Enum
Distributed
Database
(MSC (E.164)
- MSC (SIP))
86
4 Serving MSC
SIP Domain
3 Serving MSC
E.164 Address
VLR
2 UPDATE_LOCATION
HLR
84
1 UMTS
Location
Update
Request
IMSI
serving
MSC
82
SIP Proxy

Fig. 8

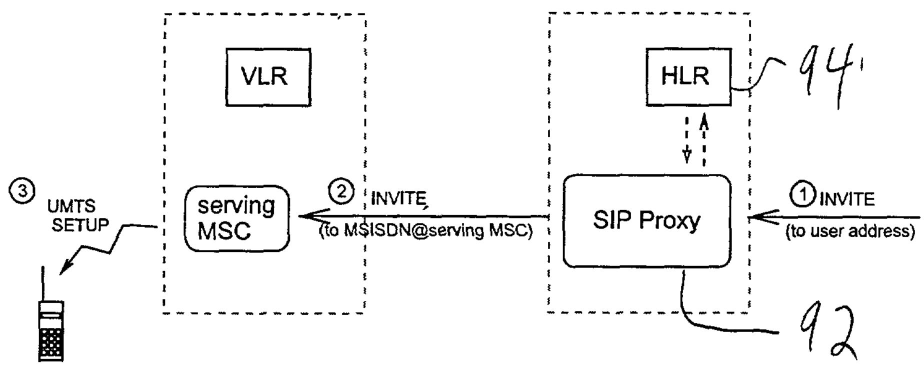


Fig. 9

Message weights

Symbol	Parameter	Value
w_{sip}	Weight of a SIP message	1.0
w_{isup}	Weight of an ISUP message	1.0
w_{dns}	Weight of a DNS message	0.5
w_{map}	Weight of a MAP message	1.5

Fig. 10

Mobility parameters

Symbol	Parameter	Value
r_{in}, r_{out}	Rate of call delivery / origination	variable
r_{bc}	Average boundary crossing rate	variable
$P_t(t)$	Boundary crossing rate prob. distribution ($P(t_0 \geq t)$)	$e^{-r_{bc}t}$
s	Call / mobility ratio	$\frac{r_{out}+r_{in}}{r_{bc}}$
P_{nr}	Prob. that a device is new to a serving MSC	50%
P_{ur}	Prob. that a device has a unique registrar at its serving MSC	20%
P_{us}	Prob. that a device has a unique serving MSC at its HLR/registrar	20%

Fig. 11

Protocol parameters

Symbol	Parameter	Value
t_{sip}	SIP registration refresh interval	3 hr
t_{dns}	DNS cache time-to-live	24 hr
c_{auth}	Number of pieces of authentication data cached at VLR	5

Fig. 12

Case	Formula
Modified Registration	
Registration	$r_{\mathrm{bc}}((8+2/c_{\mathrm{auth}})\, w_{\mathrm{map}}+$ $(2P_{\mathrm{nr}}+4P_{\mathrm{ur}})\, w_{\mathrm{dns}}+$ $4\,(1+\sum_{i=1}^{\infty} P_t(it_{\mathrm{sip}}))\, w_{\mathrm{sip}})$
Call setup	$r_{\mathrm{in}}\,(4P_{\mathrm{us}}w_{\mathrm{dns}}+1w_{\mathrm{sip}})$
Modified Call Setup	
Registration	$r_{\mathrm{bc}}\,(8+2/c_{\mathrm{auth}})\, w_{\mathrm{map}}$
Call setup	$r_{\mathrm{in}}\,(4w_{\mathrm{map}}+6P_{\mathrm{us}}w_{\mathrm{dns}}+1w_{\mathrm{sip}})$
Modified HLR	
Registration	$r_{\mathrm{bc}}((8+2/c_{\mathrm{auth}})\, w_{\mathrm{map}}$ $+2P_{\mathrm{us}}w_{\mathrm{dns}})$
Call setup	$r_{\mathrm{in}}\,(4P_{\mathrm{us}}w_{\mathrm{dns}}+1w_{\mathrm{sip}})$

Fig. 13

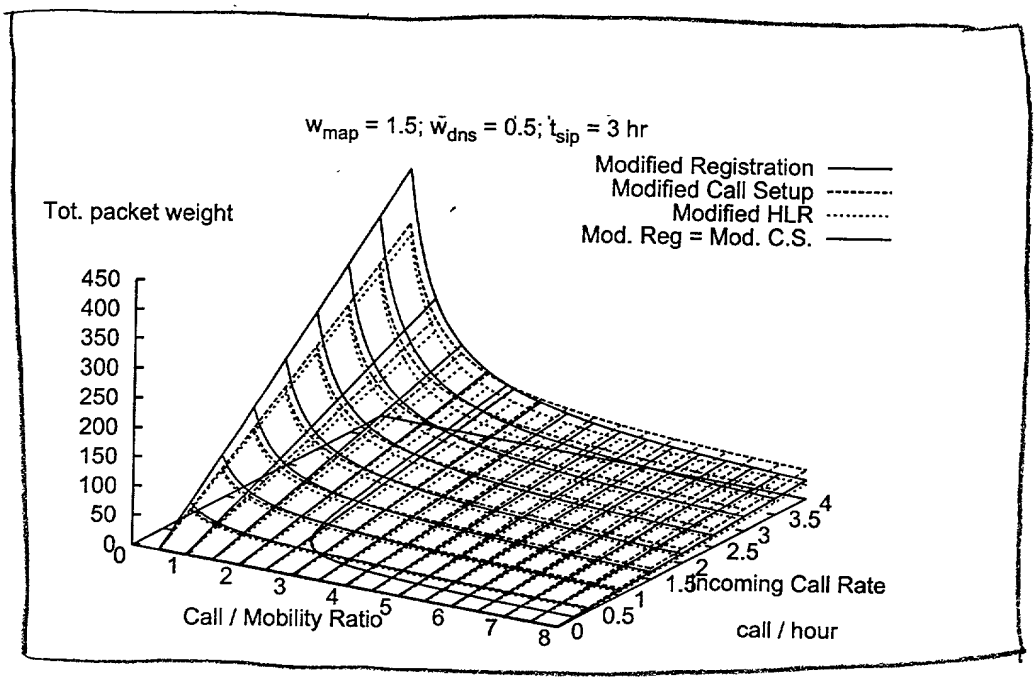

w_{map} = 1.5; $\tilde{w}_{dns}$ = 0.5; $\tilde{t}_{sip}$ = 3 hr
Modified Registration
Modified Call Setup
Modified HLR
Mod. Reg = Mod. C.S.
Tot. packet weight
450
400
350
300
250
200
150
100
50
0
0
1
2
3
4
5
6
7
8
Call / Mobility Ratio
0
0.5
1
1.5
2
2.5
3
3.5
4
Incoming Call Rate
call / hour

Fig. 14

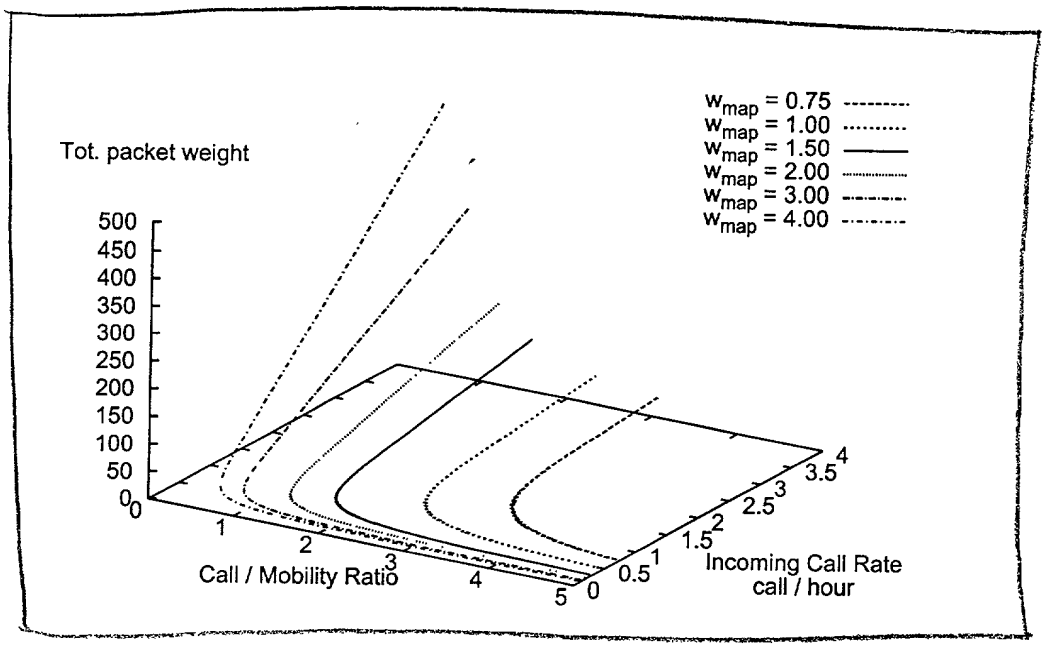

Tot. packet weight
500
450
400
350
300
250
200
150
100
50
0
0
1
2
3
4
5
Call / Mobility Ratio
0
0.5
1
1.5
2
2.5
3
3.5
4
Incoming Call Rate
call / hour
w_{map} = 0.75
w_{map} = 1.00
w_{map} = 1.50
w_{map} = 2.00
w_{map} = 3.00
w_{map} = 4.00

Fig. 15

Fig. 16

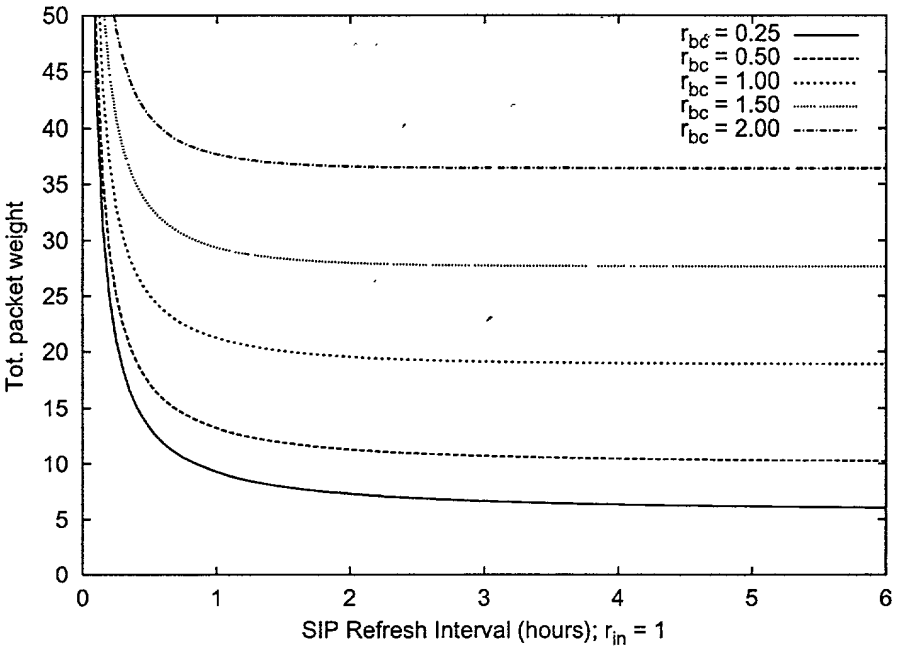

Tot. packet weight
SIP Refresh Interval (hours); r_{in} = 1
r_{bc} = 0.25
r_{bc} = 0.50
r_{bc} = 1.00
r_{bc} = 1.50
r_{bc} = 2.00
0
5
10
15
20
25
30
35
40
45
50
0
1
2
3
4
5
6

Fig. 17

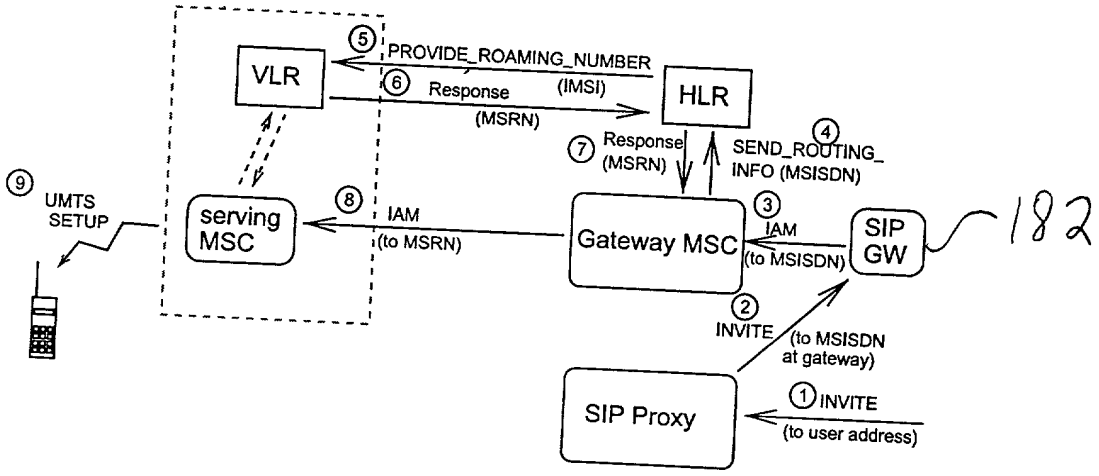

VLR
HLR
PROVIDE_ROAMING_NUMBER
Response (IMSI)
(MSRN)
Response (MSRN)
SEND_ROUTING_ INFO (MSISDN)
UMTS SETUP
serving MSC
IAM (to MSRN)
Gateway MSC
IAM (to MSISDN)
SIP GW
182
INVITE (to MSISDN at gateway)
SIP Proxy
INVITE (to user address)

Fig. 18

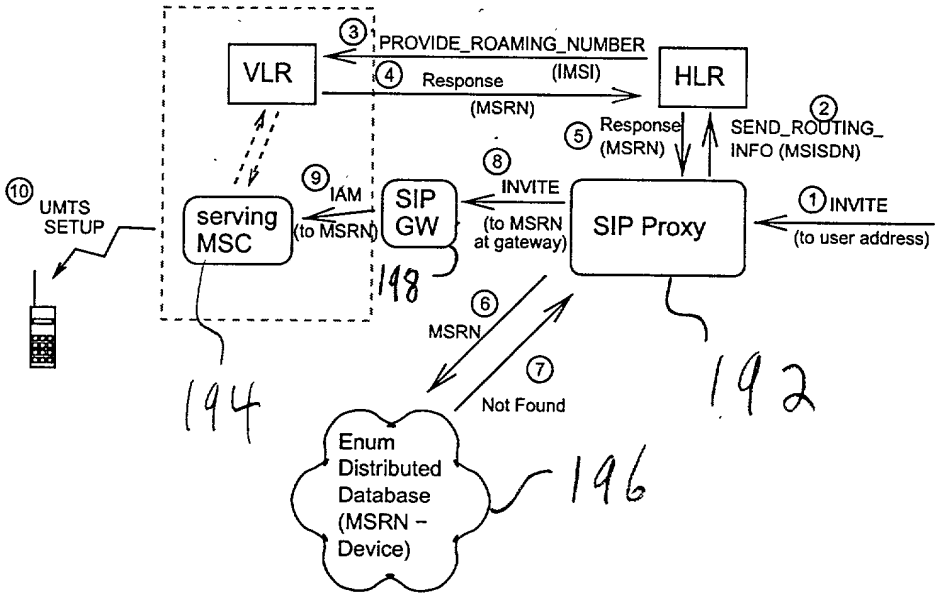

VLR
HLR
PROVIDE_ROAMING_NUMBER
Response (IMSI) (MSRN)
Response (MSRN)
SEND_ROUTING_ INFO (MSISDN)
INVITE (to user address)
SIP Proxy
INVITE (to MSRN at gateway)
SIP GW
IAM (to MSRN)
serving MSC
UMTS SETUP
MSRN
Not Found
Enum Distributed Database (MSRN – Device)
198
194
192
196

Fig. 19

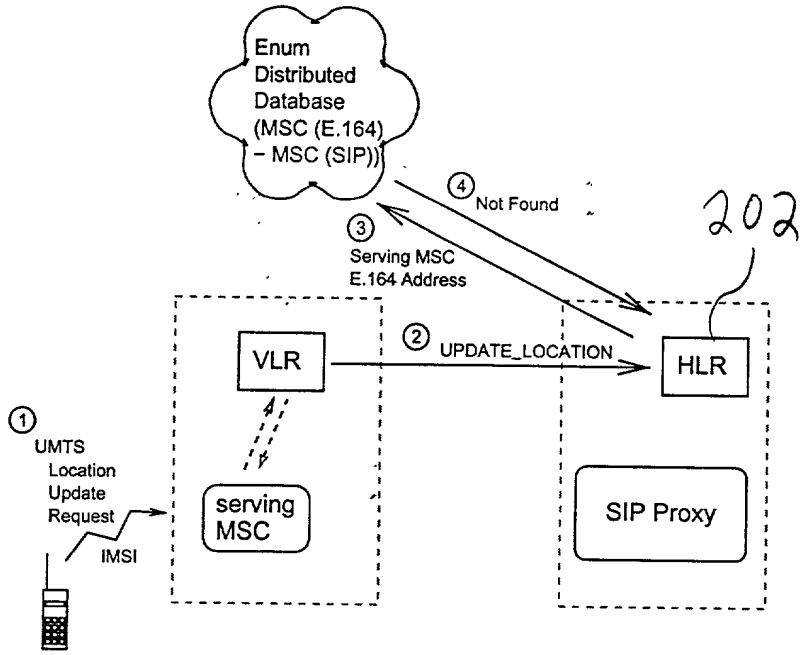


Fig.20

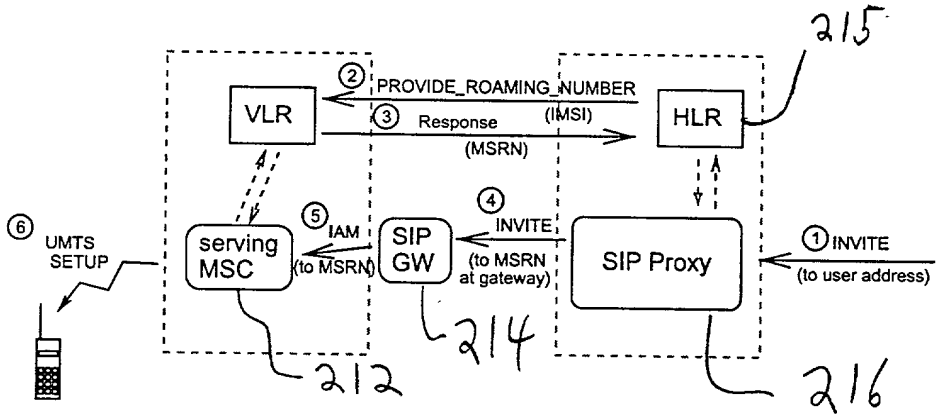


Fig.21

Case	Formula
Modified Registration	
Registration	$r_{\text{bc}}\,(8 + 2/c_{\text{auth}})\,w_{\text{map}}$
Call setup	$r_{\text{in}}\,(4w_{\text{map}} + 1w_{\text{sip}} + 2w_{\text{isup}})$
Modified Call Setup	
Registration	$r_{\text{bc}}\,(8 + 2/c_{\text{auth}})\,w_{\text{map}}$
Call setup	$r_{\text{in}}\,(4w_{\text{map}} + 6P_{\text{us}}w_{\text{dns}} + 1w_{\text{sip}} + 1w_{\text{isup}})$
Modified HLR	
Registration	$r_{\text{bc}}((8 + 2/c_{\text{auth}})\,w_{\text{map}} + 2P_{\text{us}}w_{\text{dns}})$
Call setup	$r_{\text{in}}\,(2w_{\text{map}} + 4P_{\text{us}}w_{\text{dns}} + 1w_{\text{sip}} + 1w_{\text{isup}})$

Fig. 22

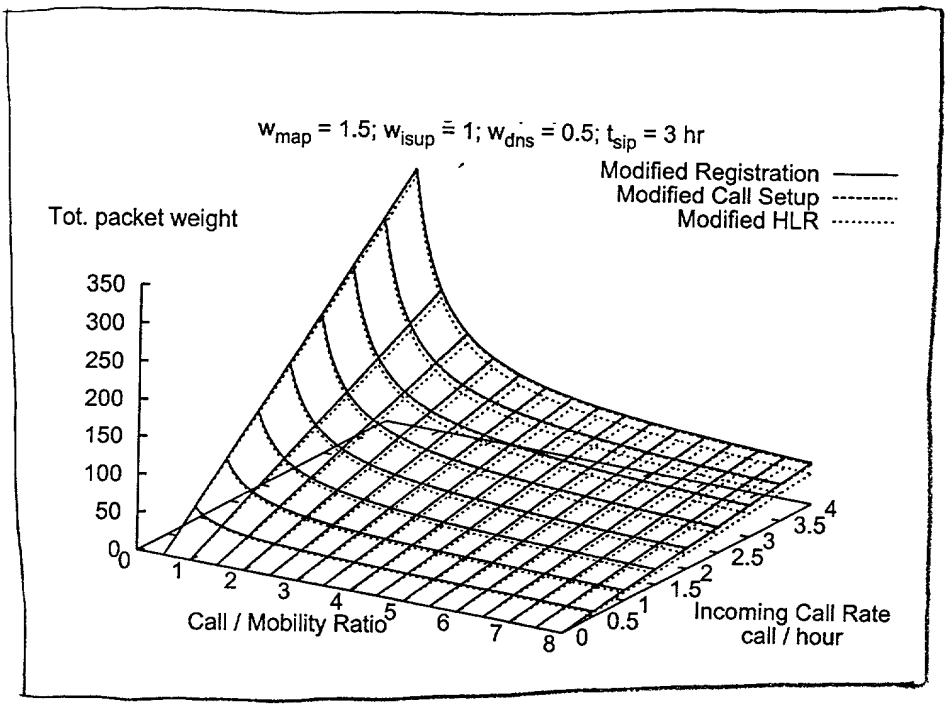

w_{map} = 1.5; w_{isup} = 1; w_{dns} = 0.5; t_{sip} = 3 hr
Modified Registration
Modified Call Setup
Modified HLR
Tot. packet weight
350
300
250
200
150
100
50
0
0
1
2
3
4
5
6
7
8
Call / Mobility Ratio
0
0.5
1
1.5
2
2.5
3
3.5
4
Incoming Call Rate
call / hour

Fig. 23

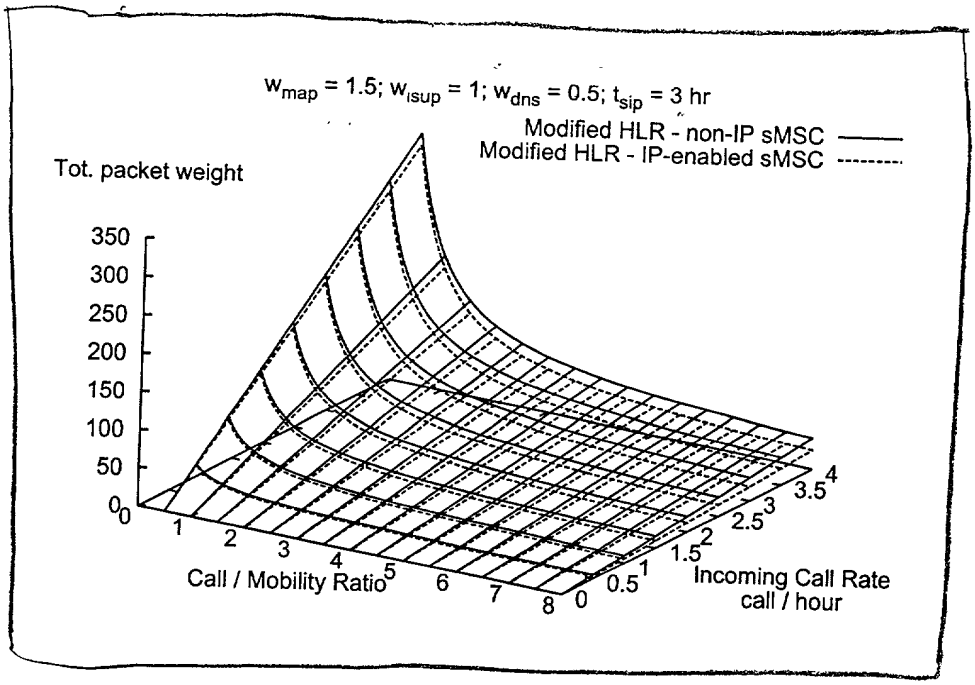

w_{map} = 1.5; w_{isup} = 1; w_{dns} = 0.5; t_{sip} = 3 hr
Modified HLR - non-IP sMSC
Modified HLR - IP-enabled sMSC
Tot. packet weight
350
300
250
200
150
100
50
0
0
1
2
3
4
5
6
7
8
Call / Mobility Ratio
0
0.5
1
1.5
2
2.5
3
3.5
4
Incoming Call Rate
call / hour

Fig. 24

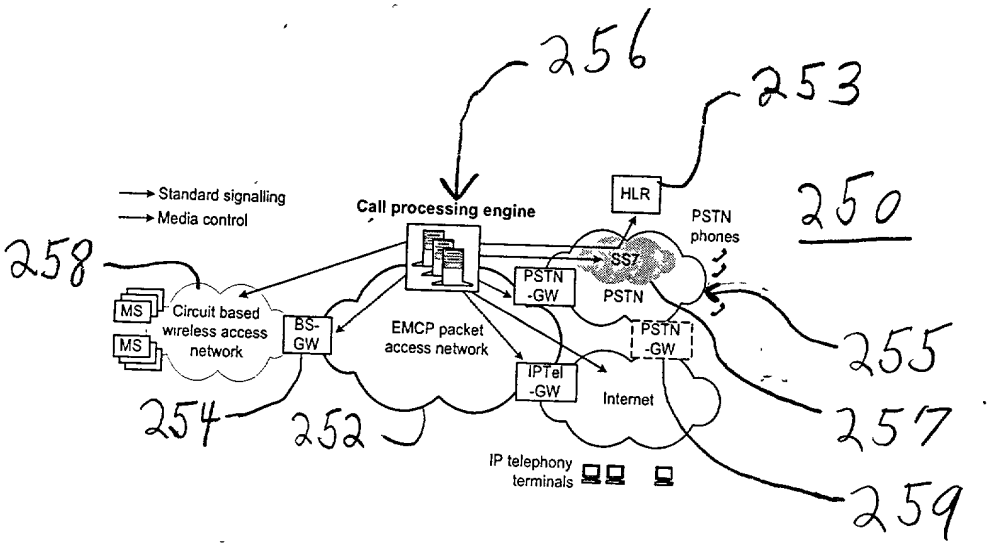

256
253
250
Standard signalling
Media control
Call processing engine
HLR
PSTN phones
258
SS7
PSTN -GW
PSTN
MS
MS
Circuit based wireless access network
BS-GW
EMCP packet access network
PSTN -GW
255
IPTel -GW
Internet
254
252
257
IP telephony terminals
259

Fig. 25

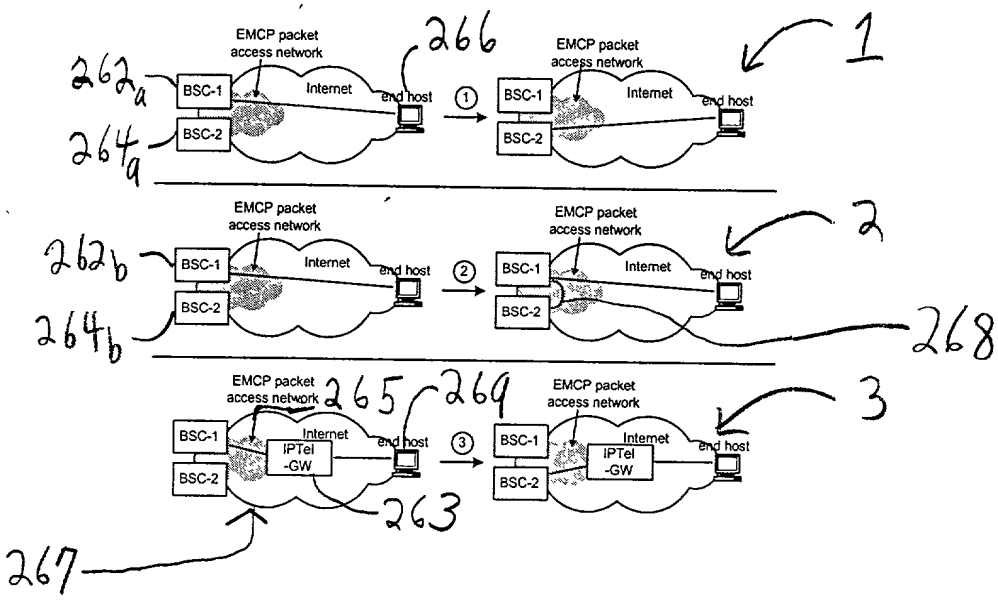

EMCP packet access network
BSC-1
BSC-2
Internet
end host
IPTel -GW
262a
264a
262b
264b
263
265
266
267
268
269
1
2
3

Fig.26

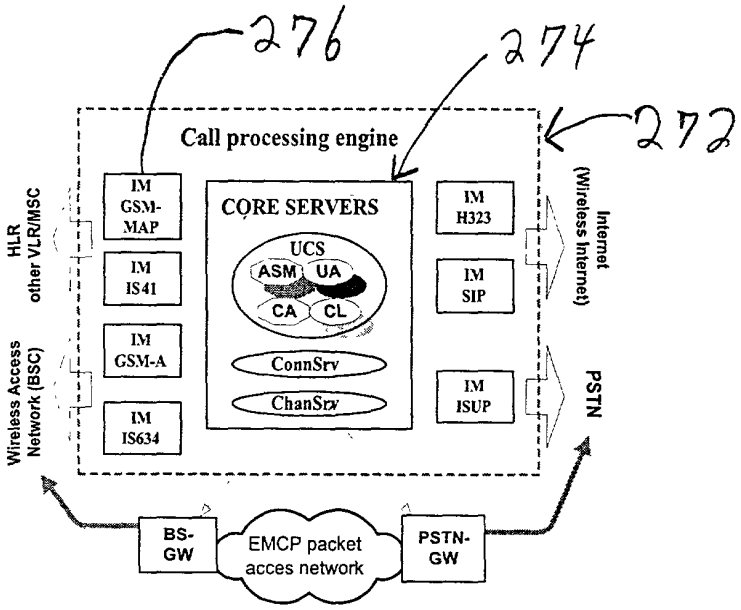

276
274
272
Call processing engine
IM GSM-MAP
IM IS41
IM GSM-A
IM IS634
CORE SERVERS
UCS
ASM
UA
CA
CL
ConnSrv
ChanSrv
IM H323
IM SIP
IM ISUP
HLR other VLR/MSC
Wireless Access Network (BSC)
Internet (Wireless Internet)
PSTN
BS-GW
EMCP packet acces network
PSTN-GW

Fig.27

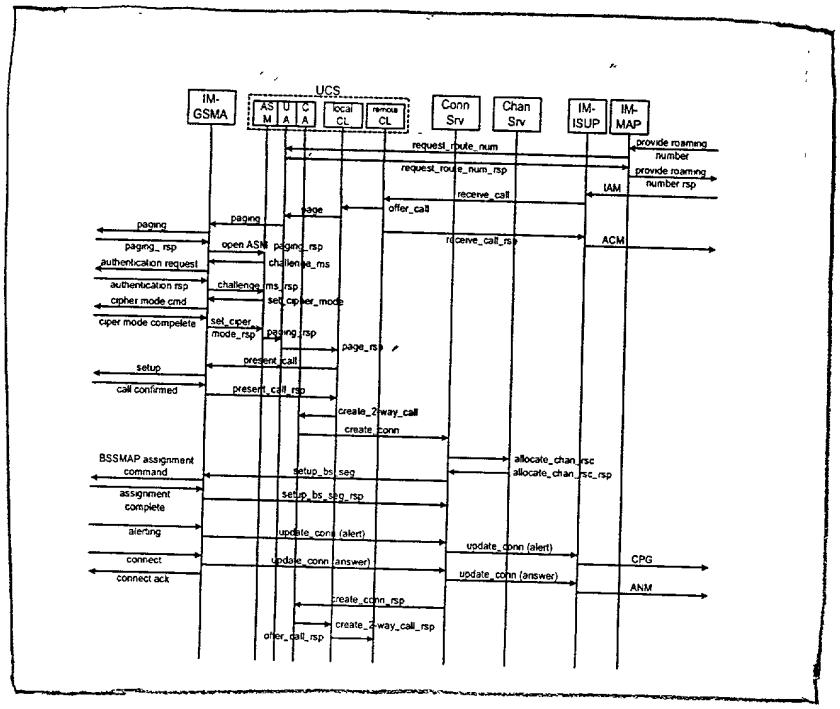

UCS
IM-GSMA
ASM
UA
CA
local CL
remote CL
Conn Srv
Chan Srv
IM-ISUP
IM-MAP
request_route_num
provide roaming number
request_route_num_rsp
provide roaming number rsp
receive_call
IAM
offer_call
page
paging
paging
paging_ rsp
open ASM
paging_rsp
receive_call_rsp
ACM
authentication request
challenge_ms
authentication rsp
challenge_ms_rsp
cipher mode cmd
set_cipher_mode
ciper mode compelete
set_ciper_mode_rsp
paging_rsp
page_rsp
present_call
setup
call confirmed
present_call_rsp
create_2way_call
create_conn
BSSMAP assignment command
allocate_chan_rsc
allocate_chan_rsc_rsp
setup_bs_seg
assignment complete
setup_bs_seg_rsp
alerting
update_conn (alert)
update_conn (alert)
CPG
connect
update_conn (answer)
update_conn (answer)
connect ack
ANM
create_conn_rsp
create_2way_call_rsp
offer_call_rsp

Fig. 28

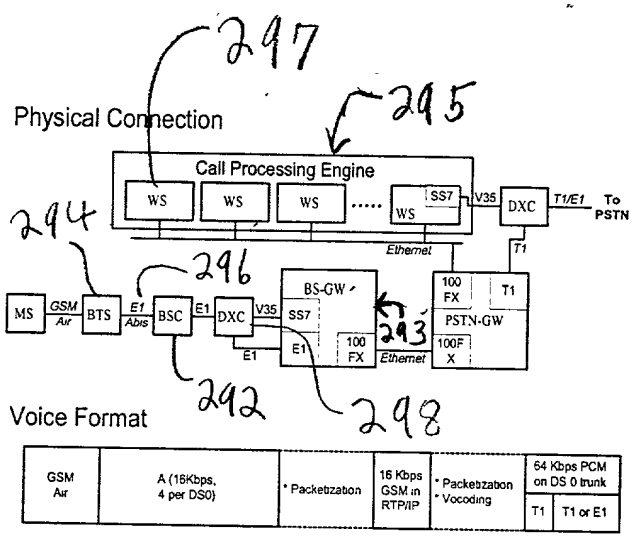

297
295
Physical Connection
Call Processing Engine
WS
WS
WS
WS
SS7
V35
DXC
T1/E1
To PSTN
Ethernet
T1
294
296
MS
GSM Air
BTS
E1 Abis
BSC
E1
DXC
V35
SS7
E1
BS-GW
100 FX
Ethernet
293
100 FX
T1
PSTN-GW
100F X
292
298
Voice Format
GSM Air
A (16Kbps, 4 per DS0)
* Packetization
16 Kbps GSM in RTP/IP
* Packetization
* Vocoding
64 Kbps PCM on DS 0 trunk
T1
T1 or E1

Fig. 29

302

INDEPENDENT PARAMETERS.

	Description	Value
P	Number of processors (system size)	4
N	Average number of registered users	[80K,400K]
l_c	Call arrival rate (Poisson)	(0.3,5.5)
r_c	Ratio of MO calls within l_c	2/3
u	Call holding time (Exponential)	90 secs
l_r	Mobile registration rate (near-Poisson)	[0.1,2.0]
r_r	Inter-MSC registration ratio within l_r	1/7

Fig. 30

312

DERIVED PARAMETERS.

	Description	Value
$l_c \cdot r_c$	MO call arrival rate (Poisson)	(0.2,3.65)
$l_c \cdot (1 - r_c)$	MT call arrival rate (Poisson)	(0.1,1.82)
$l_r \cdot r_r$	Boundary crossing rate	[0.014,0.29]
t	Call setup latency	measured

Fig. 31

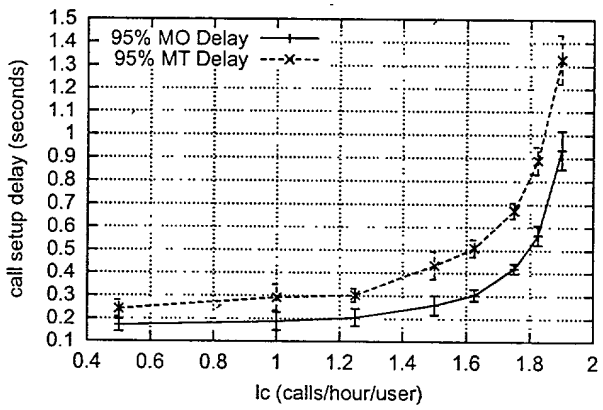

95% MO Delay
95% MT Delay
call setup delay (seconds)
lc (calls/hour/user)
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2

Fig. 32

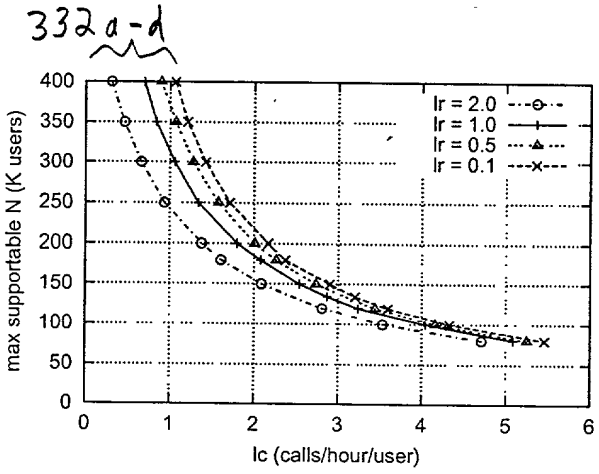


Fig. 33

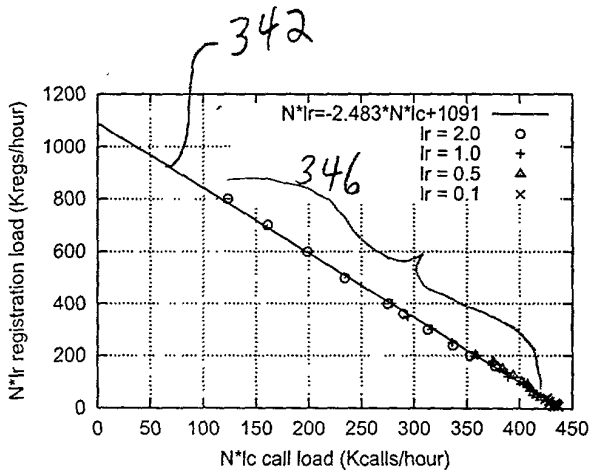


Fig. 34

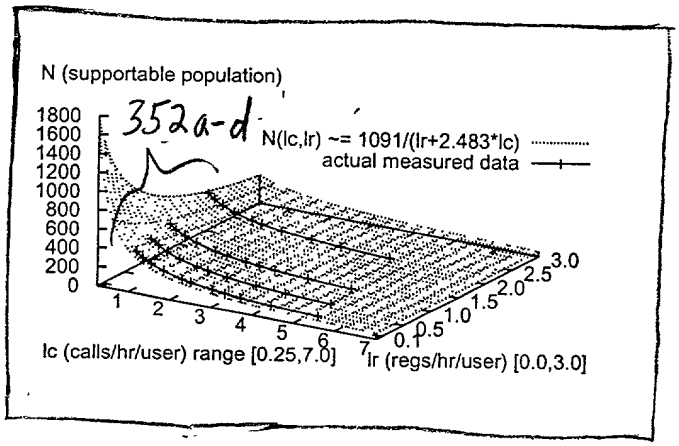


Fig. 35

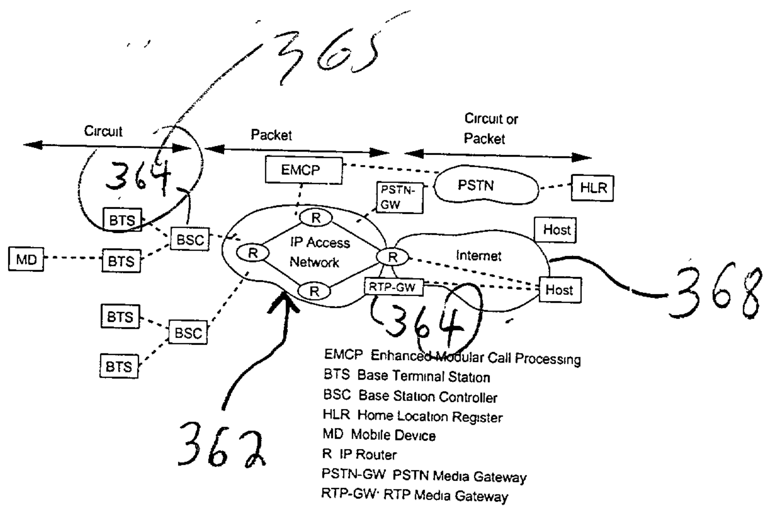
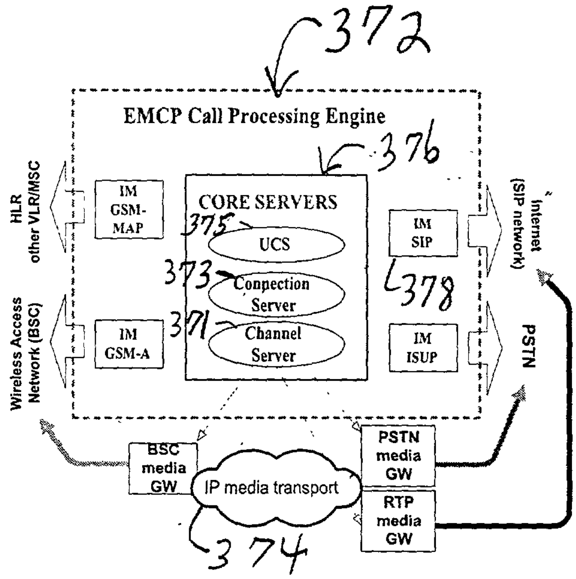

365
Circuit
Packet
Circuit or Packet
364
EMCP
PSTN-GW
PSTN
HLR
BTS
BSC
R
IP Access Network
Internet
Host
MD
RTP-GW
364
368
362
EMCP Enhanced Modular Call Processing
BTS Base Terminal Station
BSC Base Station Controller
HLR Home Location Register
MD Mobile Device
R IP Router
PSTN-GW PSTN Media Gateway
RTP-GW RTP Media Gateway

Fig. 36



Structure of EMCP Call Processing Engine

Fig. 37